

Transient behavior between multi-cell flow states in ferrofluidic Taylor-Couette flow

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We investigate transient behaviors induced by magnetic fields on the dynamics of the flow of a ferrofluid [1] in the gap between two concentric, independently rotating cylinders. Without applying any magnetic fields, we uncover emergence of flow states constituted by a combination of a localized spiral state in the top and bottom of the annulus and different multi-cell flow states with toroidally closed vortices in the interior of the bulk. However, when a magnetic field is presented, we observe the transient behaviors between multi-cell states passing through two critical thresholds in a strength of an axial (transverse) magnetic field [2]. Numerical simulations are carried out by solving the ferrohydrodynamical equation of motion using the Niklas approximation [3]. Before the first critical threshold of a magnetic field strength, multi-stable states with different number of cells can be observed. After the first critical threshold, we find the transient behavior between the three- and two-cell flow states. For stronger magnetic fields or after the second critical threshold, we discover that multi-cell states to disappear and a localized spiral state remains stimulated in the system.

Without applying any magnetic fields, we found the emergence of two flow states constituted by a combination of a localized spiral state (SPI_l) in the top and bottom of the annulus and different multi-cell flow states (SPI_{l+2v} , SPI_{l+3v}) with toroidally closed vortices in the interior of the bulk ($SPI_{l+2v} = SPI_l + SPI_{2v}$ and $SPI_{l+3v} = SPI_l + SPI_{3v}$). The appearing of these multi-stable states is based on the initial conditions.

Applying any magnetic field and changing its strength can trigger transitions among various flow states, for example, the two-cell and three-cell flow states. The emergence of the flow states, dynamical evolution, and transitions among the various flow states can be summarized in detail, as follows. By increasing the axial [transverse] magnetic field strength, we first identify a transition from SPI_{l+3v} [(SPI_{l+2v}) to SPI_{l+2v} [SPI_{l+3v}], respectively. However, for strong enough magnetic fields, we discover the second transition only leaving a SPI_l state behind.

Although the flow states under fairly large magnetic fields (s_x or s_z) are SPI_l , there is a significant difference between two final SPI_l states. For applying the strong transverse magnetic field (s_x), SPI_l is orientated close to top and bottom lid located in the Ekman vortex regime. But SPI_l under the strong axial magnetic field (s_z) is orientated more towards the center of the bulk. According to the different type of magnetic fields, SPI_l state can move to or away from the Ekman region.

As to expect, the transitions between the multi-cell flow states are always accompanied by a change in the wavelength and wavenumber, respectively. However, in the present study the symmetry breaking effect (a stimulated two-cell mode [4, 5]) of the transverse magnetic field is obviously present, but plays a significant minor role than in other studies. It becomes more and more pronounced for the larger magnetic field strength s_x and s_z .

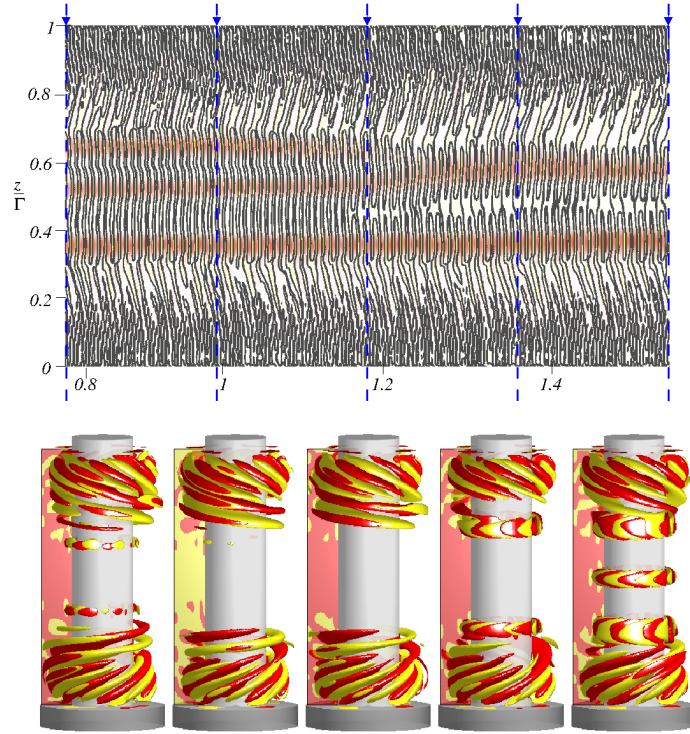


Figure 1: Transitions from SPI_{l+3V} to SPI_{l+2V} . *Top*: Space-time plot of the azimuthal vorticity η during the transition at $r = r_1 + 0.1d$. Red (dark gray) and yellow (light gray) correspond to positive and negative values, with $\eta \in [-440, 440]$. *Bottom*: Snapshots of corresponding vortex structures during the transition.

References

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